

Effects of thinning on microsites and natural regeneration in a *Larix olgensis* plantation in mountainous regions of eastern Liaoning Province, China

LIU Zu-gen^{1,2}, ZHU Jiao-jun^{1**}, HU Li-le¹, WANG He-xin³, MAO Zhi-hong^{1,2}, LI Xiu-fen^{1,2} ZHANG Li-jun⁴

¹ Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, 110016, P. R. China

² Graduate School, Chinese Academy of Sciences, Beijing, 100039, P. R. China

³ Dalian University, Dalian, 116622, P. R. China

⁴ Forestry Bureau of Qingyuan Manzu Autonomous County, Liaoning Province, 113300, P. R. China

Abstract: In order to understand the effects of thinning on microsite conditions and natural regeneration in the larch plantation, thinning experiment was conducted in a 40-year-old *Larix olgensis* plantation in Qingyuan County in eastern Liaoning Province, China in 2003–2004. Five thinning treatments (0%, 10.2%, 19.8%, 29.7% and 40.3% thinned) were designed on the same site. After thinning, canopy openness and the microsite conditions such as photosynthetic photon flux density (PPFD), soil moisture content, and soil temperature were measured in one growing season. Meanwhile, the investigation of natural regeneration was conducted at the end of the growing season. The results showed that the canopy openness increased with the increase of thinning intensities. PPFD and soil temperature and soil moisture content in different soil layers were positively relative with canopy openness after thinning. The richness of regenerating tree species did not significantly increase ($p=0.30$) after one growing season since thinning, but the regeneration density and frequency of tree species increased significantly ($p<0.05$). In addition, the number of regenerating tree species increased, and the increment was correlated with the characteristics of individual tree species. The increasing percentage of regenerating seedlings of the shade-intolerant tree species was more than that of shade-tolerant tree species. Among the investigated regeneration species, the biggest response of seedling emergency to the canopy openness was *Phellodendron amurense*. This paper confirmed the following conclusions: after thinning, the variety of regenerating tree species was correlative with the characteristics of regenerating tree species, and the distribution of unthinned trees and the site conditions in the investigated larch plantation were the additional factors influencing the regeneration.

Keywords: *Larix olgensis* plantation; Thinning; Microsite; Natural regeneration

CLC number: S754

Document code: A

Article ID: 1007-662X(2005)03-0193-07

Introduction

It is well known that a plantation has higher productivity, but it also has many problems such as simple structure, unstable community, and vulnerable to plant diseases and insect pest. Further, these problems may lead to a decline of land capability of the plantation. Additionally, ecological functions of the plantations are not as good as the natural forests. Therefore, many countries have asserted actively to carry out “nature-approximating forestry” (Franklin and Spies 1985; Bauer 1990), which practiced natural regeneration. Moreover, the natural regeneration has lower cost, only accounting for one fourth of that of artificial regeneration, i.e., the natural regeneration is a good management way with low cost and high productivity (Jia and Yang 2002). The natural regeneration of forests, therefore, has fitted modern sustainable management of forests and biodiversity protection (Dong 2001; Martins *et al.* 2002). Thinning, as one of the management measures, can affect many aspects of the natural regeneration of forests, such as reducing forest canopy density, increasing the light availability, changing temperature and moisture

content of soil, and influencing the quantity and quality of litter (Zhu *et al.* 2003b). Up to now, the study of effects of thinning on natural regeneration of forests has been widely conducted (Marilou and Messier 2002), and many studies focused on the effects of different thinning intensities on environmental factors, which would affect the survival, establishment and growth of seedlings (David 2002; Sophie 2003; Zhu *et al.* 2003b; Simard *et al.* 2004). Generally, thinning can create canopy openness or gaps, which are critical in the community dynamic of many forest types (Stokes *et al.* 1995; Gray and Spies 1996; Gobbi and Schlichter 1998). In a mature forest stand, strictly describing, when trees are cut, gaps with different sizes can be created, thus, many canopy gaps are present in thinned forests. However, due to the heterogeneous distribution of canopy gaps, the light availability to the forest ground has a large spatial variation within a plantation (Mizunaga 2000). Many studies discussed the effects of only one gap on the light availability, although the light availability to a seedling growth was not only affected by only one gap (Mizunaga 2000). Additionally, the reported researches on evaluating the effects of thinning on natural regeneration also mainly focused on the way of one gap on the microsite conditions (Clinton 2003; Gagnon *et al.* 2003; Schumann *et al.* 2003), few studies have been done on integrating effects of many gaps on the microsite conditions and the natural regeneration (Mizunaga 2000).

Larch plantations are the main forest types in northeastern China, e.g., they covered more than $2.0 \times 10^6 \text{ hm}^2$ in the mountainous regions of eastern Liaoning Province, and most of them are around 40 years old. These larch plantations can provide not only timber production, but ecological service functions (water

Foundation item: This study was supported by “the 100-Young-Research Project” of Chinese Academy of Sciences and National Natural Science Foundation of China (30371149)

Biography: LIU Zu-gen (1975-), male, Ph D candidate of Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China. E-mail: liuzugen2002@yahoo.com.cn

Received date: 2005-04-10

Accepted date: 2005-06-20

Responsible editor: Song Funan

**Corresponding author: E-mail: zrms29@yahoo.com

conversation) as well (Hao and Wang 1998). Therefore, it is important and necessary to improve the timber productivity and conserve the ecological functions of these plantations. According to the theory of “nature-approximating forestry”, the best way to sustain the productivity and ecological functions of larch plantations is to develop these larch plantations into natural forests through natural regeneration. Thinning, as one of the most important management techniques for plantations, is undoubtedly indispensable method for improving natural regeneration (Jiang *et al.* 1994; Palik and Pederson 1996; Krauchi *et al.* 2000; Zhu *et al.* 2003b). It is necessary to understand the relationships between thinning (canopy openness) and natural regeneration. The objectives of this study are as follows: first to quantify the size of canopy openness of different thinning intensities in larch plantations; then to confirm the relationships between canopy openness and photosynthetic photon flux density (PPFD), temperature and water content of soil; at last, to analyze the effects of canopy openness created by thinning on the regeneration and the response of regenerating tree species to the thinning within one growth season in the larch plantation.

Methods

Study site

The study was conducted in a larch plantation in Qingyuan Experimental Forest of Institute of Applied Ecology, Chinese Academy of Sciences, which located in Qingyuan County in eastern Liaoning Province (Fig. 1). The larch plantation was composed of *Larix olgensis*, even-aged (40 years old), with a planting density of $1800 \text{ stems} \cdot \text{hm}^{-2}$. The area of experimental plantation is 6.4 hm^2 , with a gentle slope (around 15°) toward south, and soil type is a typical dark brown forest soil, with a thickness of 60 to 80 cm. The larch plantation is surrounded by natural secondary forests, which are mainly composed of *Quercus mongolica*, *Pinus koraensis* (plantation), *Betula* spp., *Acer* spp., *Tilia* spp., *Fraxinus* spp., and *Juglans mandshurica*. The climatic conditions are characterized by warmer summer and colder winter. Annual mean temperature is 3.9–5.4°C. The coldest month is January and the warmest month is July. Annual mean precipitation is 700–1 200 mm and rainfall occurs from June to August, the frost-free period lasts 150 days, and the growing season of vegetation is from April to September.

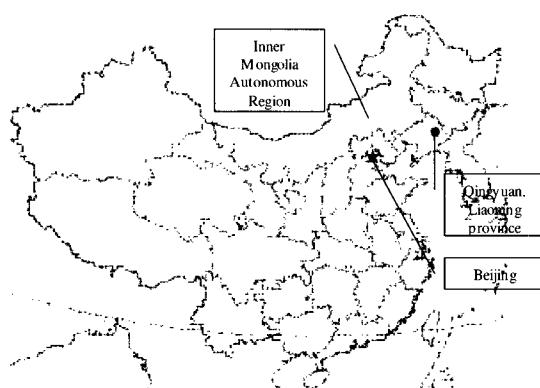


Fig. 1 Location of the experimental site (Qingyuan County, Liaoning Province, China, N41°51.102', E124°54.543').

Experimental design and treatments

The experiment included five thinning levels applied on the same site, which was divided into five almost equivalent treatment plots. The thinned stems and rates were determined by stem number and thinning pattern. From east to west, those plots were referred to: treatment A: an unthinned, 0.0%, treatment B: dead and DBH<10cm trees were cut away, 10.2% thinned; treatment C: dead and DBH<15 cm trees were cut away, 19.8% thinned; treatment D: dead and DBH<18 cm trees were cut away, 29.7% thinned; and treatment E: all dead and DBH<20 cm trees were cut away, 40.3% thinned. There was a buffer zone around each treatment plot. The effective area of each treatment reached 40 m \times 40 m. Prior to thinning, in November, 2003, all trees located inside the measurement plots were identified with numbered tags, and the diameter at breast height (DBH) were measured. Trees were selected and marked for thinning, and all plots were thinned during 7th to 15th of May, 2004. Trees were cut near the root collar using chainsaws; after thinning, all the slashed wood was logged by mule-car. In each plot, five fixed points were selected to measure the microsite conditions (Fig. 2).

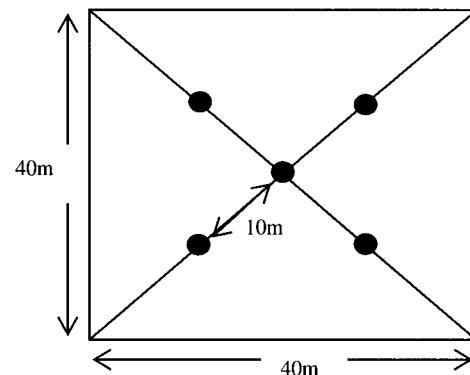


Fig. 2 Experimental layout of plot.

The solid points in the figure indicated the locations for observation of microsite conditions

Measurement of canopy openness

In order to estimate the canopy openness (Zhu *et al.* 2003a), before (on 6th of May, 2004) and after thinning (in different seasons, such as on 16th of May, 31st of August and 2nd of November, 2004), the silhouettes of hemispherical photographs were taken at five points using a 180° fisheye lens (Nikon, FC-E8, f=8–24 mm) mounted on a Nikon digital camera (Nikon, Coolpix 910, Japan, f=7–21 mm) in each plot. The camera was placed on a tripod at a height of 1.0 m above ground and orientated northerly; all photographs were taken on cloudy days or at dawn and dusk. Canopy openness was analyzed according to the process developed by Steege (1994) using CanopOn Program (Ver1.09, Takenaka's Web) and Zhu *et al.* (2003a) from the hemispherical images.

Measurement of microsite conditions

Light measurement

On clear days, photosynthetic photon flux density (PPFD) in the waveband of 400–700 nm was measured directly at the five points within each plot with Basic Quantum Meter (QMSW-SS, USA). The Basic Quantum Meter was logged as quickly as possible 20 data intervals for one hour over a period of 10 h (from 8:00 a.m. to 5:00 p.m., GMT+008) for 5 days (Mizunaga 2000).

which included July 26th, August 17th, September 2nd, September 14th, and September 23rd, in each plot. The sensor of Basic Quantum Meter was leveled at a height of 1.0 m above the ground for each reading using a bubble level located on the underside of the sensor wand. Total measured values of the ten hours were summed up to show the relative PPFD values of the day. It was important that the sensor recording incident PPFD was logged side by side of each plot. In addition, in order to understand the difference between inside forest and outside forest, a reference measurement was taken in an open area and used to determine the percentage of PPFD of the treatment plots to open area (McLaren and McDonald 2003).

Soil temperature measurement

At the five points in each plot, soil temperature was measured with a soil surface thermometer (Tianjin, China), which were set on soil surface every half month from July 15th to November 15th, soil temperature was recorded intervals for one hour over a period of 10 h (from 8:00 a. m. to 5:00 p. m.) during the clear days.

Soil moisture content

Soil moisture contents in layers of 0–10 cm, 20–30 cm and 40–50 cm were measured in each plot. After scarifying the litters, soil samples were collected every half month from July 15th to December 15th. Three cores (can volume = 100 mL) at each layer were taken for all of the treatments. The measurement of soil samples was referred to the method established by Nanjing Institute of Soil Science, CAS (1978).

Census of seedling regeneration

Each plot was divided into 2 m×2 m subplots, and total four hundred subplots were set up in each plot for observing the emergence and growth of regeneration seedlings. In each subplot, the regeneration seedlings were investigated twice (May and September) after thinning. The seedling species, number, height and base stem diameter of regenerating trees were recorded during the investigation.

Statistic analysis

Due to the heterogeneity of gap distribution after thinning, the average values of environmental factors (such as gap openness, PPFD and soil temperature) of the five points in each plot were used in the analysis of the effects of thinning on the microsite conditions of the larch plantation. Species richness was computed by the Magalef index (Zhang 2004). Regression analysis was applied to test the relationships between canopy openness or thinned intensities and species richness of regenerated seedlings, seedling density and frequency. In addition, analysis of variation (ANOVA) was used to determine the significance of effects of canopy openness or thinning treatment on PPFD, soil temperature and moisture content by software of SPASS 11.50.

Results

Canopy openness of stands at different thinning intensities

Canopy openness at 1.0 m above the ground of each thinned treatment plot in different periods was shown in Fig. 3. Before thinning (May 6th, 2004), the canopy openness varied from 15.26% to 15.96% in the five thinned plots, which meant that canopy openness was not significantly different ($p>0.05$) in the

experimental larch plantation. However, soon after thinning (May 16th), it was obviously that canopy openness increased with the increasing of thinning intensities (Fig. 3). The canopy openness in treatments A, B, C, D, and E was 0%, 0.43%, 1.35%, 2.71%, and 4.45%, respectively, and the difference was significant ($p<0.05$). In each plot, canopy openness measured in November was larger than those measured in August and in May because of needle falling in November (Fig. 3). Canopy openness measured in May and August after thinning was the largest in treatment E, i.e., the most intensely thinned treatment. However, the largest canopy openness value measured in November did not occur in treatment E. This result may be explained by the presence of remaining individuals, the height of surrounding forest canopy, and the topography (Martins and Rodrigues 2002; Marilou and Messier 2002).

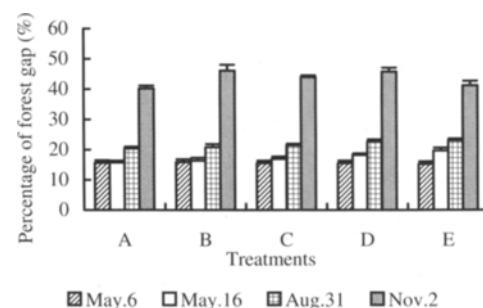


Fig. 3 Canopy openness at different seasons in measurement plots

Bars represent standard errors (n=5); A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned

Microsite conditions

Light

The quantity of light reached the forest floor was correlative with the size of canopy openness (Kobayashi *et al.* 2000; Myers *et al.* 2000; Zhu *et al.* 2002). At these measured plots, light environment of different thinning treatments exhibited the same tendency, i.e. with the increase of canopy openness from treatment A to E, PPFD also increased (Fig. 4), in which the difference was significant ($p<0.005$). The percentage of PPFD of the treatment plots to open area were shown in Fig. 5, and from treatment A to treatment E, the PPFD percentage gradually increased. In different periods, light availability in forest understory was different ($p=0.028$), which was relative with weather condition and canopy openness; furthermore, the difference of light availability increased with canopy openness increasing (Fig. 4).

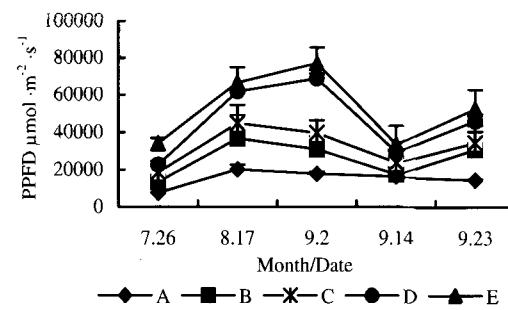


Fig. 4 PPFD at different dates in various plots.

Bars represent standard errors (n=5); A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned.

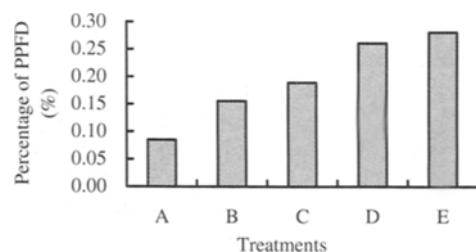


Fig. 5 Ratios of PPFD inside the thinned plots to that in the open area on 17th, August, 2004

A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned.

Soil temperature

Soil surface temperature increased with the increment of canopy openness, but the increasing extent was various in different periods, which became bigger with the increase of canopy openness (Fig. 6). Soil surface temperature got to the largest values in mid-August (Aug. 18th) for all thinned plots, and the differences of the largest values were greater among the thinned treatments.

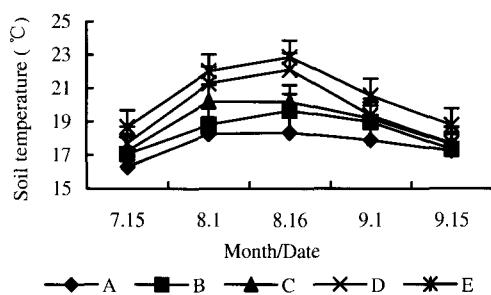


Fig. 6 Soil surface temperature of different periods in each plot.

Bars represent standard errors (n=5); A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned.

Soil moisture content

The average of soil moisture content at the three layers was correlated with the thinning intensities (canopy openness) positively, i.e. the highest soil moisture content appeared in treatment E, and the lowest in treatment A (Fig. 7).

Seedling natural regeneration

Seedling emergency had significantly difference between various thinning treatments (Table 1), but the difference mainly appeared in seedling number not in seedling species. The species of regenerating seedling mainly included *Cornus controversa*, *Betula costata*, *Pinus koraiensis*, *Juglans mandshurica*, *Sorbus pohuashanensis*, *Phellodendron amurense*, *Ulmus laciniata*, *Quercus mongolica*, *Acer mono*, *Acer tegmentosum*, *Acer pseudo-sieboldianum*, *Maackia amurensis*, *Populus davidiana*, *Fraxinus rhynchophylla*, *Ulmus japonica*, and *Tilia amurensis*. This result indicated that the response of seedling emergency to canopy openness was obviously different among those tree species, which were mainly determined by the characteristics of tree species. Number of regenerating seedling of the intolerant-shade tree species increased in each plot (Table 2), which included *P. amurense*, *J. mandshurica*, *C. controversa*, *F. rhynchophylla*, *Q. mongolica*, *F. rhynchophylla*, *A. pseudo-sieboldianum*, and *A.*

tegumentosum. Of these species, the largest difference of regenerated seedling number between the two investigations in May and September was *P. amurense* (shade-intolerant), e.g., in treatment B, it increased from 0 to 62 individuals, in treatment C, D, and E, it increased 17.22 times, 17.08 times, and 16.75 times, respectively (Table 2). However, number of regenerated seedling of tolerant-shade tree species such as *A. mono*, *U. laciniata*, *U. japonica*, *M. amurensis*, *S. pohuashanensis*, and *P. koraiensis*, in addition, and pioneer tree species of succession including *P. davidiana* and *Betula costata*, changed a little.

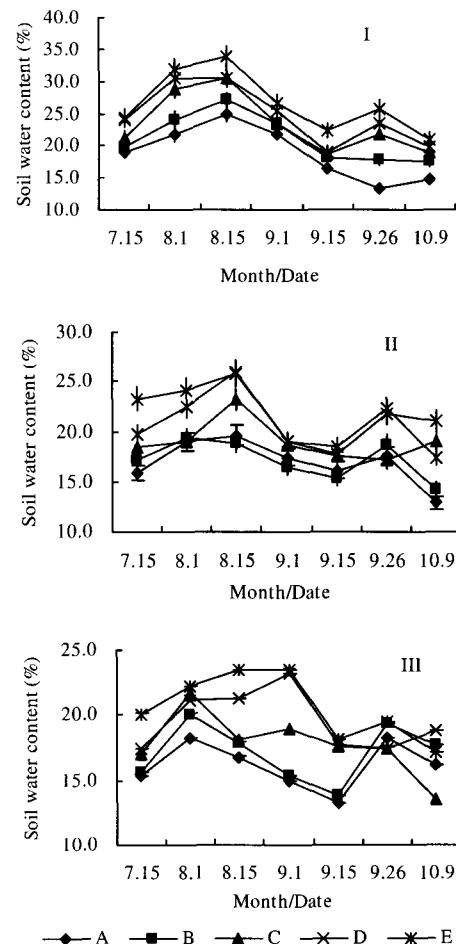


Fig. 7 Soil moisture content of different layers at each plot in various periods.

Bars represent standard errors (n=3); I: 0-10cm; II: 20-30cm; III: 40-50cm

Table 1. Regeneration description in different plots

Plots	Species richness		Regeneration density (individuals m ⁻²)		Regeneration frequency	
	May	Sept.	May	Sept.	May	Sept.
A	1.77	1.77	4.04	4.09	0.79	0.89
B	1.98	2.05	0.39	0.52	0.52	0.65
C	1.92	1.85	1.05	1.38	0.88	0.95
D	2.22	2.14	0.86	1.11	0.75	0.85
E	2.16	2.04	0.57	0.84	0.42	0.82

Note: A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned.

Change of species richness was not significant between dif-

ferent treatments ($p=0.30$) during the first growing season after gap formation by thinning, but the increases of seedling density ($p<0.01$) and frequency ($p<0.05$) were significant (Table 1). Moreover, the difference of regenerated seedling number between the two investigations in May and September increased with the increase of canopy openness (Table 2). The linear relationship was established between the increasing percentage of regenerating seedling in the two investigations and canopy openness ($R=0.8465$, $p<0.05$) (Fig. 8). In treatment A (0% thinned), seedling number almost had not changed during the observation, however, in treatment E (40% thinned), the increasing percentage of seedling was the biggest (Fig. 9) because the canopy openness was the biggest. The increasing percentage of seedling density was similar to seedling number, but the increasing percentage of seedling frequency was not related to the increase of canopy openness.

Table 2. Individuals of seedling regeneration for different tree species in different plots

Tree species	A		B		C		D		E	
	May	Sep.	May	Sep.	May	Sep.	May	Sep.	May	Sep.
<i>U. japonica</i>	23	25	-	-	-	-	-	-	15	21
<i>C. controversa</i>	29	33	33	41	40	62	2	5	47	95
<i>B. costata</i>	4	4	-	-	1	1	14	14	-	-
<i>P. koraiensis</i>	9	9	1	1	78	78	6	6	40	39
<i>J. mandshurica</i>	19	27	9	39	10	26	36	49	21	33
<i>S. pohuashanensis</i>	9	9	1	1	19	19	2	2	19	19
<i>F. rhynchophylla</i>	4172	4189	6	13	495	589	106	126	134	168
<i>M. amurensis</i>	38	36	1	1	37	56	-	-	14	16
<i>P. amurensis</i>	18	18	0	62	10	186	13	227	10	181
<i>A. pseudo-sieboldianum</i>	29	25	18	22	148	178	47	50	34	39
<i>P. davidiana</i>	21	21	54	58	121	184	5	5	49	77
<i>Q. mongolica</i>	104	113	16	19	16	28	50	77	23	27
<i>A. tegmentosum</i>	19	19	20	22	39	45	24	27	59	43
<i>A. mono</i>	285	307	230	233	11	17	518	475	41	49
<i>F. rhynchophylla</i>	55	55	21	28	26	32	8	8	21	23
<i>T. amurensis</i>	4	4	-	-	102	116	5	5	-	-
<i>P. davidiana</i>	13	13	-	-	-	-	6	8	-	-

Note: A: an unthinned, 0.0%; B: 10.2% thinned; C: 19.8% thinned; D: 29.7% thinned; and E: 40.3% thinned.

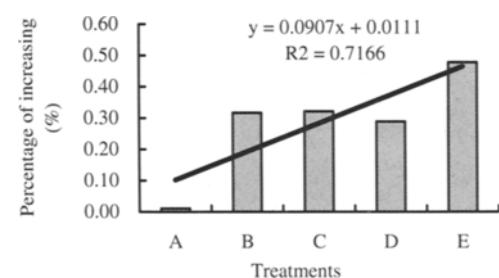


Fig.8 The increasing percentage of seedling natural regeneration in different plots between the two investigations in May and September. y: the increasing percentage; x: canopy openness; R^2 : coefficient of determination.

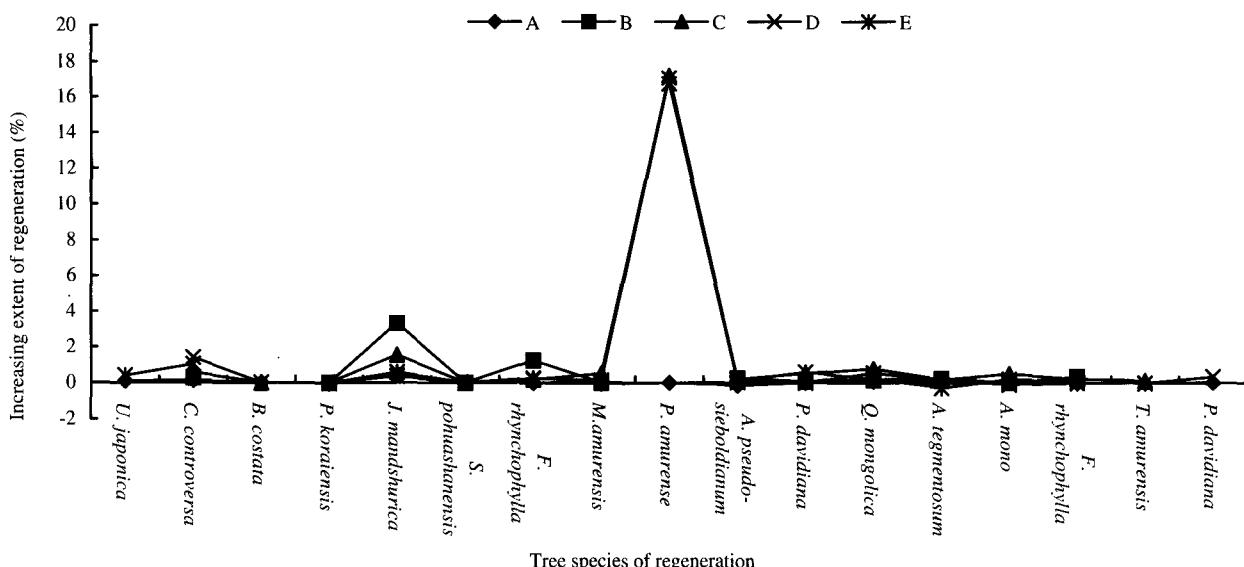


Fig.9 The increasing percentage of seedling numbers for different tree species in various plots between the two investigations in May and September

Discussion and conclusions

Effects of canopy openness created by thinning on microsite conditions

The amount of light reached to the forest floor was directly related to the size of the canopy openness (Meer *et al.* 1999). The canopy of unthinned stand allowed little sunlight to pass through, but the canopy of thinned stand allowed more amount of light reach the forest floor (Zhu *et al.* 2003b). Consequently, the micro-environment in large canopy openness was brighter than that in small canopy openness, which would be critical for the seedling emergence, establishment and growth (Ogasawara 1988). In addition, light intensity of forest understory was determined in large part by seasonal and diurnal variations of the sun, weather, topographic position, and forest canopy structure (Rich *et al.* 1993; Mitchell 2000).

Temperature was the necessary and important factor for plant growth and regeneration (Zhang *et al.* 2002). The decrease of canopy openness would make light availability increase; accordingly, soil temperature would vary and generally increase with increase of thinning intensity (Hu and Zhu 1999). Soil moisture condition varied greatly according to the canopy openness (Ochiai *et al.* 1994). In this experiment, the soil moisture content was the highest in the plot with the most intensely thinned (treatment E), which might be explained by the reduction of evaporation and diffusion (Breda *et al.* 1995; Dong *et al.* 1997). Furthermore, thinning reduced canopy water interception and positively influenced through fall (Aussenac and Granier 1987), while soil moisture content was correlative with canopy density of forest, soil temperature, rainfall, and other factors of soil and topography (Hu *et al.* 1999). Additionally, the moisture content in the top soil (0-10 cm), where seedling root systems were mainly distributed, might be the most significant for seedling survival and growth (Ochiai *et al.* 1994). Observations from this study showed that the moisture content of the top soil was much higher in thinned plots than in the unthinned plot.

Effects of canopy openness created by thinning on natural regeneration

Regeneration in forest was controlled by both above and under-ground environmental factors, of which, light availability above ground and soil moisture content under ground played important roles (Wang *et al.* 1998). Thinning created canopy openness (gap), which increased light level (Sophie 2003). Canopy openness can be known as the main factor affecting the regeneration of seedling. After thinning, the environment factors such as light, moisture, heat, physical and chemical characteristics of soil, and the coverage of vegetation would be changed, which increased the number, density and frequency of seedlings (Table 1). These results supported the findings of other researches that the more seedling density and number in thinned treatment plots were likely to be the combined consequence of increased light availability (Gerhardt 1996; Laurent *et al.*; 2003 Zhu *et al.* 2003b). In this investigation, seedling density or number and frequency were increased after thinning, but no new tree species of regeneration, except in treatment B where only found the *P. amurense* increased, were observed after thinning (Tables 1, 2). The characteristics of tree species was considered as one of the most important factors influencing the distribution of regenerated seedlings because light availability was favorable to the seedling emergence of intolerant-shade tree species but not favorable to the regeneration of intolerant-shade tree species (Dong

and Wang 2003). In this study, seedling number of many intolerant-shade tree species such as *P. amurense*, *J. mandshurica*, *Q. mongolica* increased, but tolerant-shade tree species did not or rarely increased. On the other hand, the site conditions and the distribution of remaining trees were likely to contribute to those consequences because there were more differences in seedling number before those treatment plots were thinned. In the investigated site, soil moisture was relatively humidity and soil nutrient was good (Lei and Zhou 1993), moreover, many intolerant-shade seed-trees surrounding the experimental site, which could supply enough seeds. Therefore, the increasing percentage of regenerating seedlings of the shade-intolerant tree species was more than that of shade-tolerant tree species.

Acknowledgements

We thank Mr. Kang Hong-zhang, Ms. Fan A-nan and Ms. Xu Mei-ling for their helpful discussion on this paper. We also thank Mr. Fan Bing-ren and Mr. Chen Guang-hua for their help in data collection.

References

- Aussenac, G. and Granier, A. 1987. Effect of thinning on water stress and growth in Douglas fir [J]. Canadian Journal of Forest Research, **18**: 100-105.
- Bauer, F. 1990. Zeitgema be waldwirtschaft [J]. AFZ, **28-29**: 719-720.
- Breda, N., Granier, A., and Aussenac, G. 1995. Effects of thinning on soil and tree water relationship, transpiration and growth in an oak forest (*Quercus petraea* (Matt.) Liebl.) [J]. Tree-Physiology, **15**: 295-206.
- Clinton, B.D. 2003. Light, temperature, and soil moisture response to elevation, evergreen understory, and small canopy gaps in the southern Appalachians [J]. Forest Ecology and Management, **186**: 243-255.
- Comeau, P.G. and Heineman, J.L. 2003. Predicting understory light microclimate from stand parameters in young paper birch (*Betula papyrifera* Marsh.) stands [J]. Forest Ecology and Management, **180**: 303-315.
- David, P. 2002. Twenty-year results of precommercial thinning in a balsam fir stand [J]. Forest Ecology and Management, **168**: 177-186.
- Dong Guangping. 2001. Management and renewal of savage forest in Japan [J]. World Forestry Research, **24**(4): 57-64. (in Chinese)
- Dong Xibin and Wang Lihai. 2003. Impacts of cutting intensity on volume increment and regeneration of different forests [J]. Scientia Silvae Sinicae, **39**(6):122-125. (in Chinese).
- Dong Xibin, An Jingrui and Han Yuhua. 1997. Effect of harvesting intensity on natural regeneration [J]. Jilin Forestry Science and Technology, **126**(1): 23-25, 15. (in Chinese).
- Franklin, J.F. and Spies, D.A. 1985. Modifying Douglas-fir management regimes for non-timber objectives [M]. In: Douglas-fir management for the future, 373-379.
- Gagnon, J.L., Jokela, E.J., Moser, W.K. and Huber, D.A. 2003. Dynamics of artificial regeneration in gaps within a longleaf pine flatwoods ecosystem [J]. Forest Ecology and Management, **172**: 133-144.
- Gerhardt, K. 1996. Effects of root competition and canopy on survival and growth of tree seedling in a tropical seasonal dry forest [J]. Forest Ecology and Management, **82**: 33-48.
- Gobbi, M. and Schlichter, T. 1998. Survival of *Austrocedrus chelensis* seedlings in relation to microsite conditions and forest thinning [J]. Forest Ecology and Management, **111**: 137-146.
- Gray, A.N. and Spies, T.A. 1996. Gap size, within-gap position and canopy structure effects on conifer seedling establishment [J]. Journal of Ecology, **84**: 635-645.
- Hao Zhanqing and Wang Lihua. 1998. Water conservation capacities of soil

- with major forest types in mountainous regions of eastern Liaoning Province [J]. *Chinese Journal of Applied Ecology*, **9**(3): 237–241. (in Chinese).
- Hu Jianwei and Zhu Chengqiu. 1999. The impacts of intermediate felling on forest environment [J]. *Journal of Northeast Forestry University*, **27**(3): 65–67. (in Chinese)
- Jia Yunfei and Yang Yanlan. 2002. Primary discussion on improving natural regeneration in Xiaoxing'an Mountains [J]. *Forestry Design Reconnaissance*, (2):11–12. (in Chinese)
- Jiang Fengqin, Zhu Jiaojun, Zhou Xinhua and Lin Hemin. 1994. Theory of protective maturity and regeneration of shelterbelt [J]. *Chinese Journal of Applied Ecology*, **5**(4): 337–341. (in Chinese).
- Kobayashi, M. and Kamitani, T. 2000. Effects of surface disturbance and light level on seedling emergence in a Japanese secondary deciduous forest. *Journal of Vegetation Science*, **11**: 93–100.
- Krauchi, N., Brang, P. and Schonenberger, E. 2000. Forest of mountainous region, gaps in knowledge and needs [J]. *Forest Ecology and Management*, **132**: 73–82.
- Laurent, M., Antoine, N. and Guiot J. 2003. Effects of different thinning intensities on drought response in Norway spruce (*Picea abies* (L.) Karst.) [J]. *Forest Ecology and Management*, **183**: 47–60.
- Lei Zeyong and Zhou Fengyan. 1993. Studies on the physicochemical characteristics of forest soil in the eastern mountainous region of Liaoning province [J]. *Journal of Shenyang Agricultural University*, **24**(4): 313–316. (in Chinese)
- Marilou, B. and Messier, C. 2002. Variation in canopy openness and light transmission following selection cutting in northern hardwood stands: an assessment based on hemispherical photographs [J]. *Agricultural and Forest Meteorology*, **110**: 217–228.
- Martins, S.V. and Rodrigues, R.R. 2002. Gap-phase regeneration in a semideciduous mesophytic forest, south-eastern Brazil [J]. *Plant Ecology*, **163**: 51–62.
- McLaren, K.P. and McDonald, M.A. 2003. The effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jaranaica [J]. *Forest Ecology and Management*, **183**: 61–75.
- Meer, P.V.D., Digan, P. and Savench, A.G. 1999. Effect of gap size on seedling establishment, growth and survival at three years in mountain ash (*Eucalyptus regnans* F.M) forest in Victoria, Australia [J]. *Forest and Ecology Management*, **117**: 33–42.
- Mitchell, S.J. 2000. Stem growth responses in Douglas fir and Sitka spruce following thinning: Implications for assessing wing firmness. *Forest Ecology and Management*, **135**:105–114.
- Mizunaga, H. 2000. Prediction of PPFD variation at forest floor in a thinned Japanese cypress plantation [J]. *Forest Ecology and Management*, **126**: 309–319.
- Myers, G.P., Newton, A.C. and Melgarejo, O. 2000. The influence of canopy gap size on natural regeneration of Brazil nut (*Bertholletia excelsa*) in Bolivia [J]. *Forest Ecology and Management*, **127**: 119–128.
- Nanjing Institute of Soil Science, Chinese Academy of Sciences (CAS). 1978. *Physical and chemical analysis of soil* [M]. Shanghai: Science and Technology Press. (in Chinese).
- Ochiai, Y., Okuda, S. and Sato, A. 1994. The influence of canopy gap size on soil water condition in a deciduous broad-leaved secondary forest in Japan [J]. *Journal of Forest Research*, **7**: 308–314.
- Ogasawara, R. 1988. Physiological and ecological studies on the growth of Japanese black pine forests on sand dunes [J]. *Research Bulletin of Tottori University Forestry*, **17**: 37–137 (in Japanese).
- Palik, B.J. and Pederson, N. 1996. Overstory mortality and canopy disturbance in longleaf pine ecosystems [J]. *Canadian Journal of Forest Research*, **26**: 2035–2047.
- Rich, P.M., Clark, D.B., Clark, D.A and Oberbauer, S.F. 1993. Long-term study of solar radiation regimes in a tropical wet forest using quantum sensors and hemispherical photography [J]. *Agricultural and Forest Meteorology*, **65**: 107–127.
- Schumann, M.E., White, A.S. and Witham, J.W. 2003. The effects of harvest-created gaps on plant species diversity composition, and abundance in a Maine oak-pine forest [J]. *Forest Ecology and Management*, **176**: 543–561.
- Simard, S.W., Trevor, B.H. and Cameron I.R. 2004. Pre-commercial thinning effects on growth, yield and mortality in even-aged paper birch stands in British Columbia [J]. *Forest Ecology and Management*, **190**: 163–178.
- Sophie, E.H. 2003. The effect of thinning intensity on the below – canopy light environment in a Sitka spruce plantation [J]. *Forest Ecology and Management*, **179**: 341–349.
- Wang, Z.Q. Wang, Q.C. and Chen, Q.S. 1998. Spatial heterogeneity of soil nutrient in old growth forests of Korean pine [J]. *Journal of Forestry Research*, **9**: 240–244.
- Zhang Jintun. 2004. *Quantitative Ecology* [M]. Beijing: Science Press, p87. (in Chinese)
- Zhang Yiping, Wang Jinxin, Ma Youxin, et al. 2002. The temporal-spatial distribution of temperature on the surface roughness of the tropical secondary forest gap in Xingshuangbanna, Yunnan Province [J]. *Scientia Silvae Sinicae*, **38** (6): 1–5. (in Chinese)
- Zhu Jiaojun, Li Fengqin., Matsuzaki, T. and Gonda, Y. 2002. Influence of thinning on regeneration in a coastal *Pinus thunbergii* forest [J]. *Chinese Journal of Applied Ecology*, **13**(11): 1361–1367. (in Chinese)
- Zhu, J.J., Matsuzaki, T. and Gonda, Y. 2003a. Optical stratification porosity as a measure of vertical canopy structure in a Japanese coastal forest [J]. *Forest Ecology and Management*, **173**(1–3): 89–104.
- Zhu, J.J., Matsuzaki, T., Li, F.Q. and Gonda, Y. 2003b. Effects of gap size created by thinning on seedling emergence, survival and establishment in a coastal pine forest [J]. *Forest Ecology and Management*, **182**: 339–354.